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Barcelona, 4th November 2015

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

CIUDADES COMO CENTROS DE MODELIZACIÓN CIENTÍFICA

Jornada sobre Biosfera y Ciudades

Albert Soret Miravet
Earth Sciences Department at BSC

Objective and outline

Objective: to introduce air quality and climate modelling systems to explore their potential applications at urban scales.

Outline:

- Introduction to:
  - BSC activities
- Air quality
  - Urban areas
  - Air quality in Europe
  - Case studies
- Climate change
  - Exposure and vulnerability of urban areas
  - Case studies
- Future work
- Conclusions

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Introduction

Barcelona Supercomputing Center

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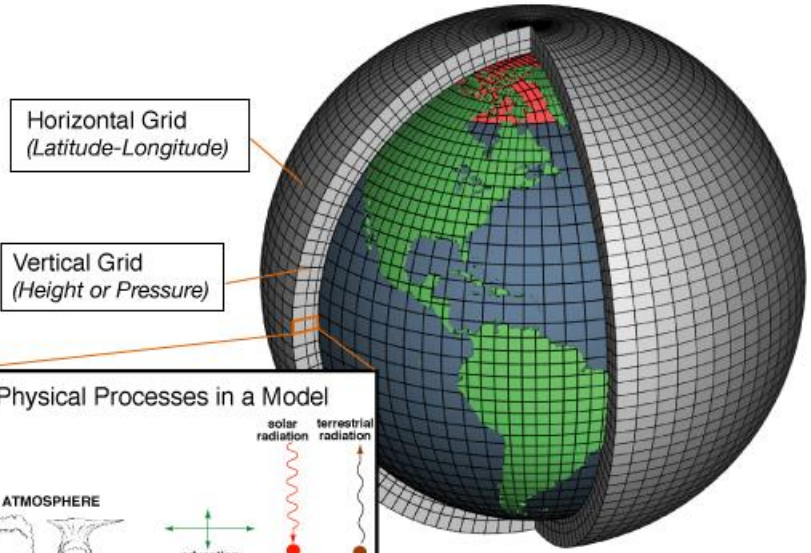
EXCELENCIA SEVERO OCHOA

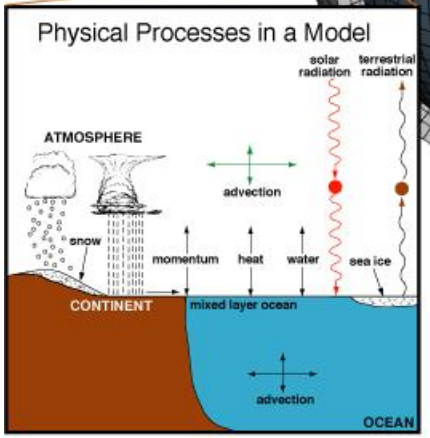
- Created in 2005; 350 employees
- Research, develop and manage information technology
- Facilitate scientific progress and its application in society

Earth Science Department

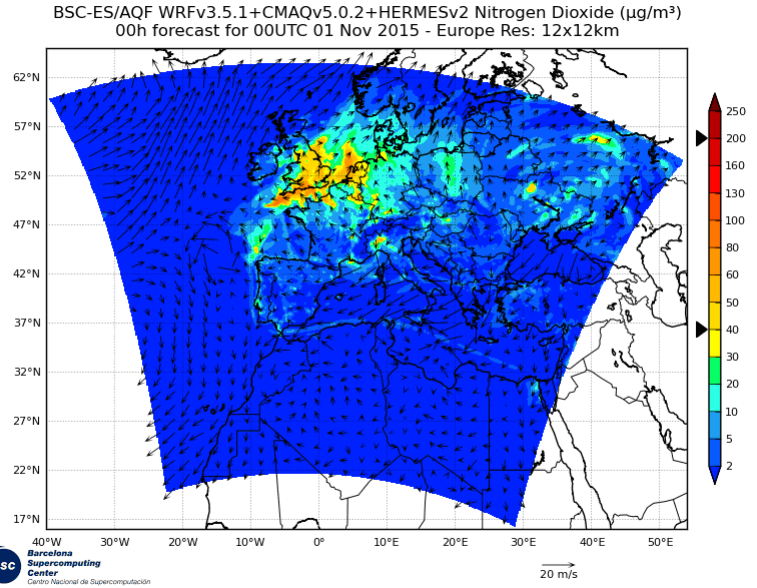
- Atmospheric composition modelling
- Climate prediction modelling
- Computational Earth Sciences
- Earth Sciences Services

Earth sciences modelling: climate and air quality modelling



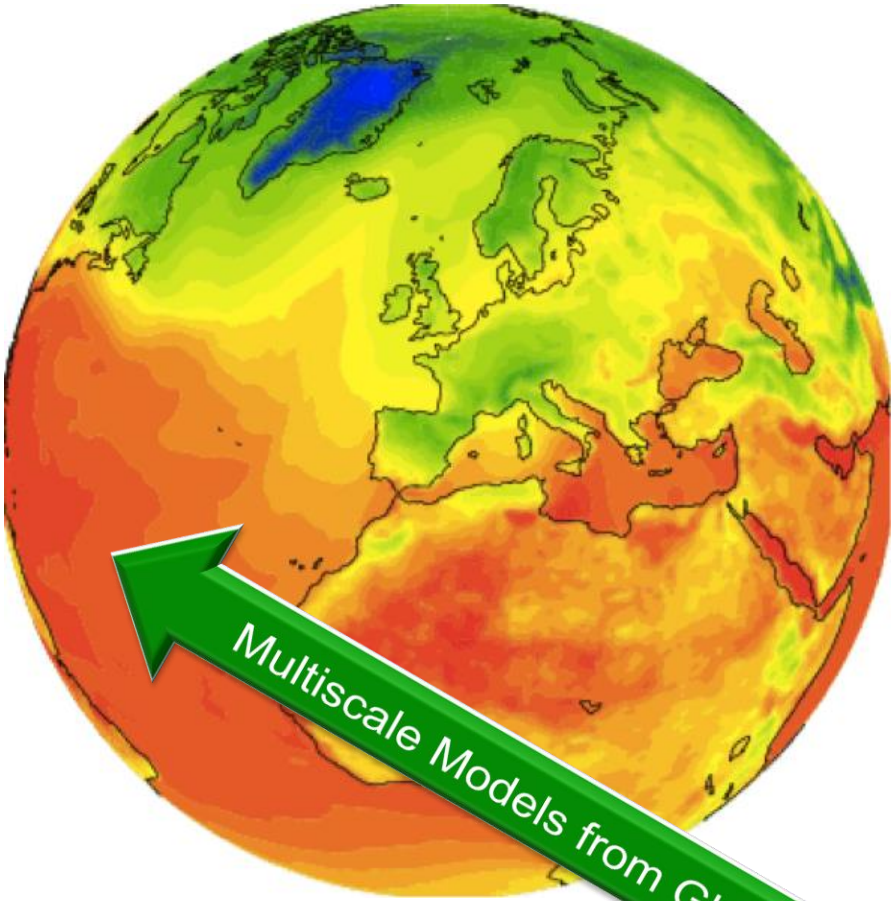


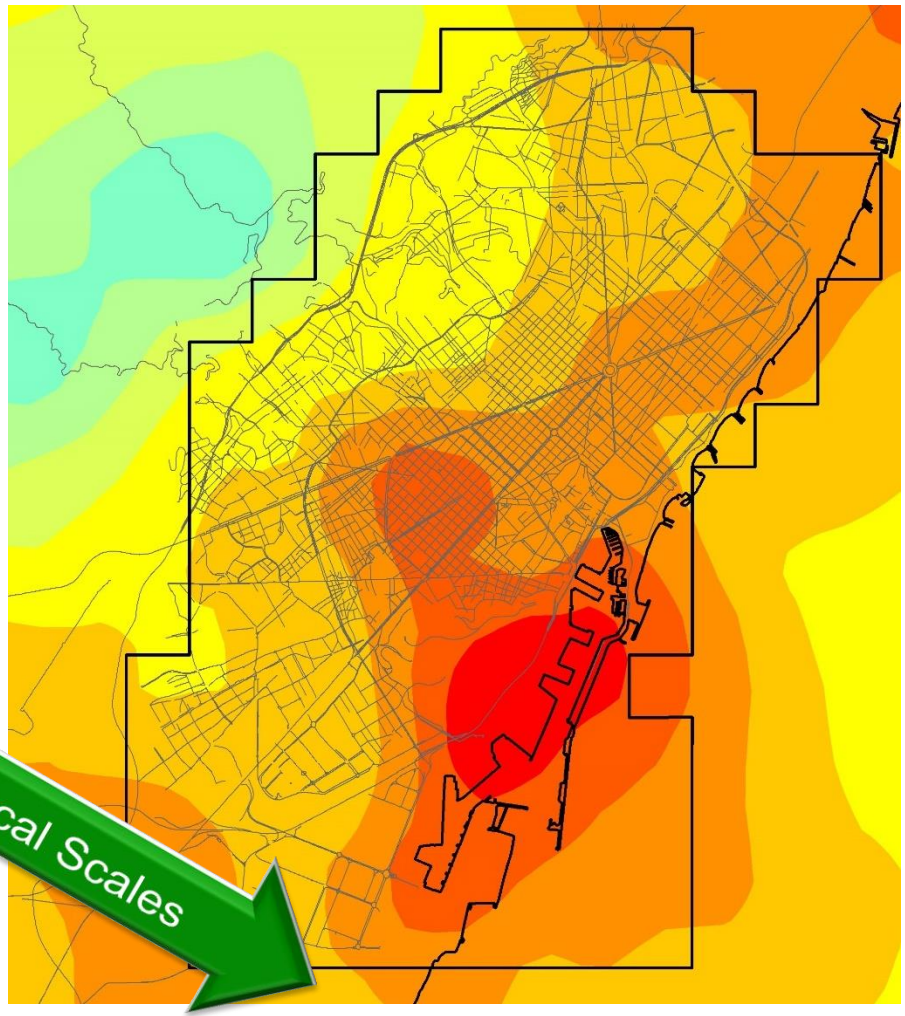
Towards modelling the Earth system

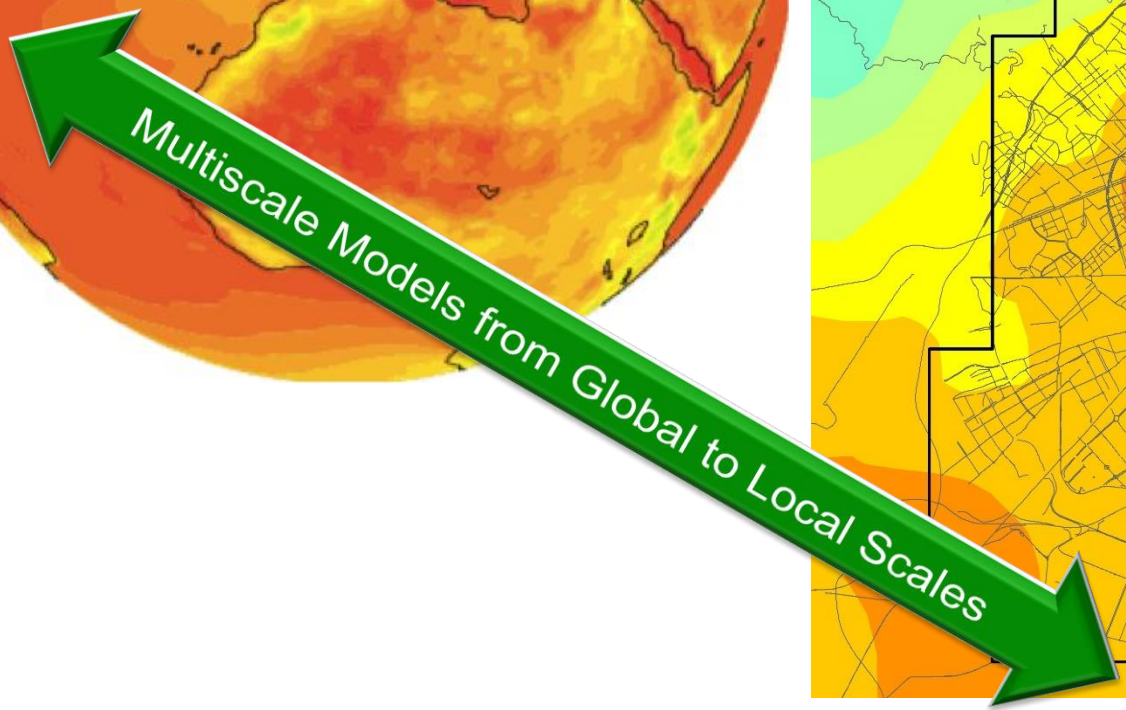


Spatial scales

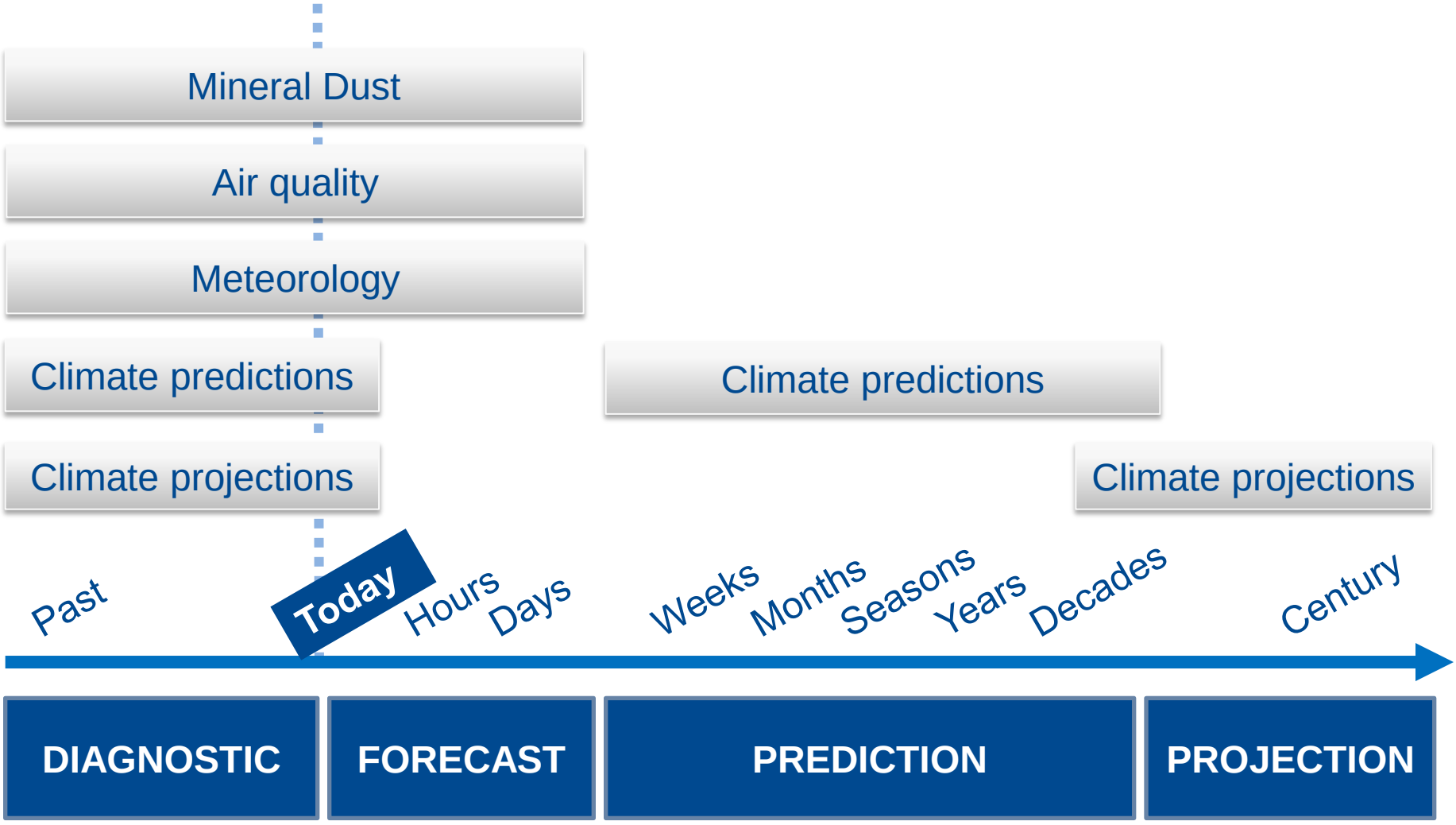
Multi-scale models from global to local scales







Temporal scales



Air quality and climate modelling systems in urban areas. Framework at BSC

Air quality modelling systems

- Air quality diagnostic studies: the case of Santa Cruz de Tenerife
- Air quality forecast system: CALIOPE
- Air quality management measures
  - Road transport: e.g. the use of cleaner fuels and technologies. Fleet electrification.
  - Industrial emissions
  - Port emissions, etc.

Climate modelling systems

- Climate prediction systems
- Climate projection systems
- Downscaling techniques

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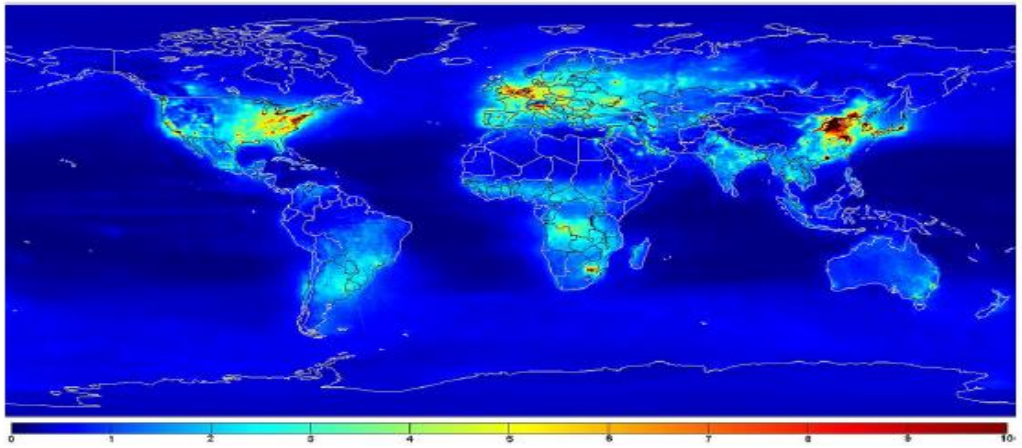
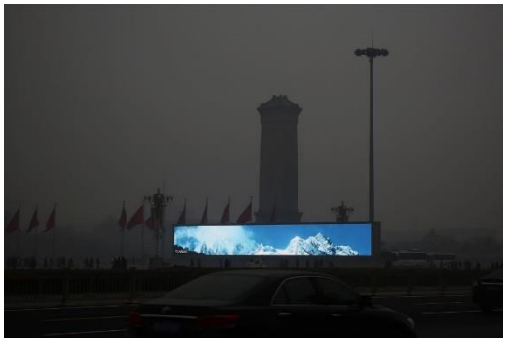
Air quality

Air pollution in urban areas



OMI tropospheric NO_2 vertical column densities, 2005 average (1015 molecules/cm2) (Wenig et al., 2008).



Beijing

Barcelona

Madrid

Istanbul

Mexico DF

Santiago de Chile

Air pollution and urban areas: causes

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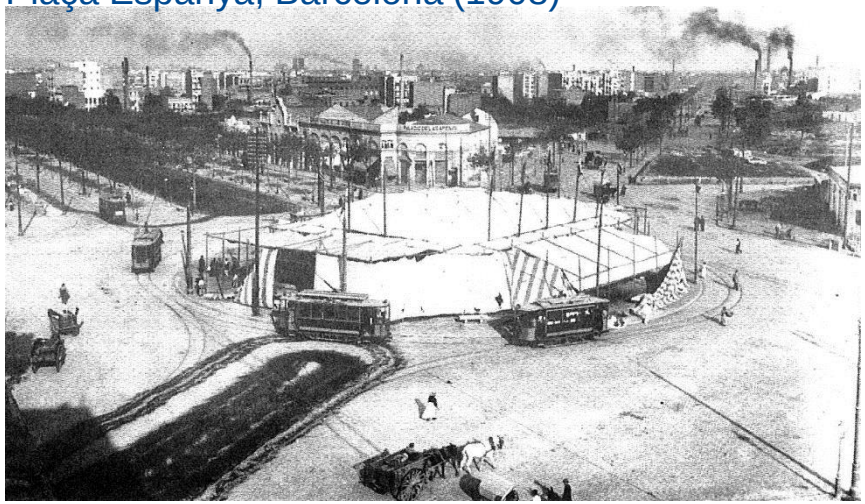
Plaça Espanya, Barcelona (1908)

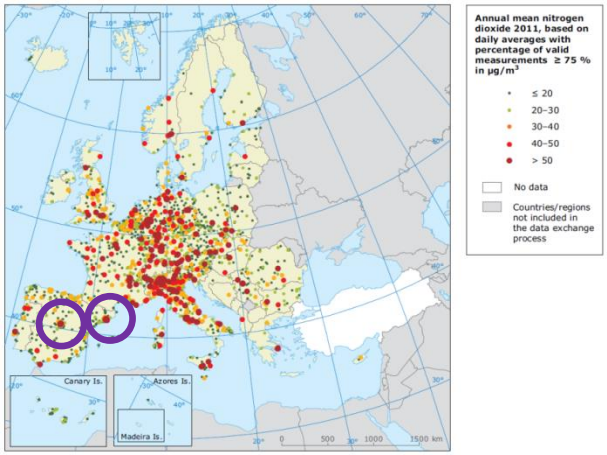


Plaça Espanya, Barcelona (2014)

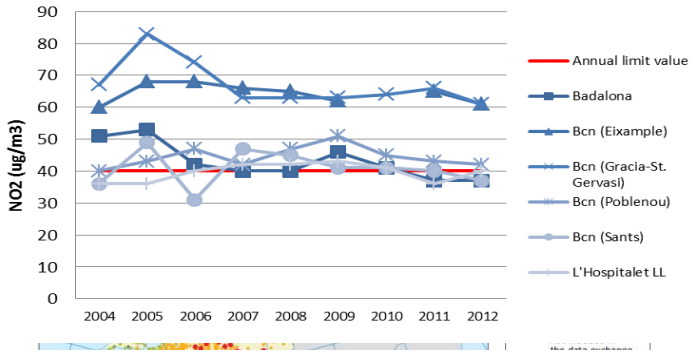
C/ Gran de Gràcia, Barcelona (1908)

C/ Gran de Gràcia, Barcelona (2014)

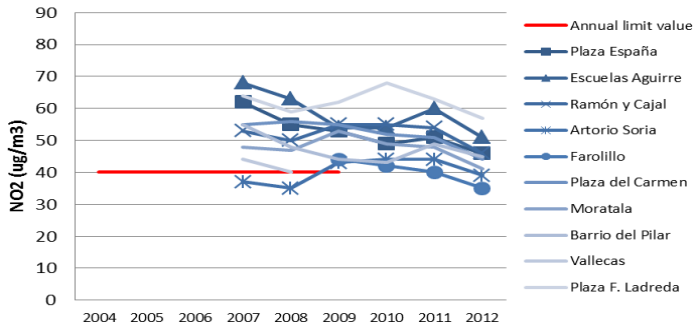
Air pollution in Europe



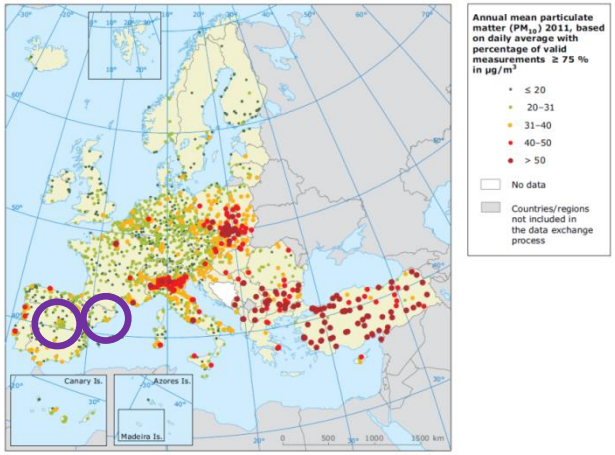
Barcelona NO_2 trends; yearly average concentration



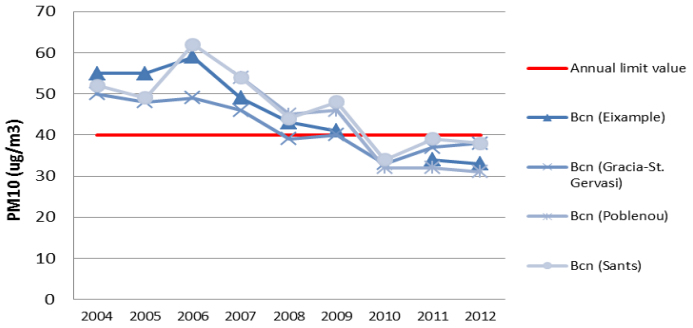
Madrid NO_2 trends; yearly average concentration



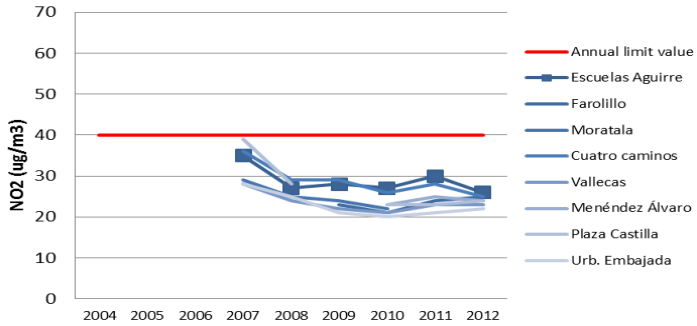
H O_3



Barcelona PM_{10} trends; yearly average concentration



Madrid PM_{10} trends; yearly average concentration

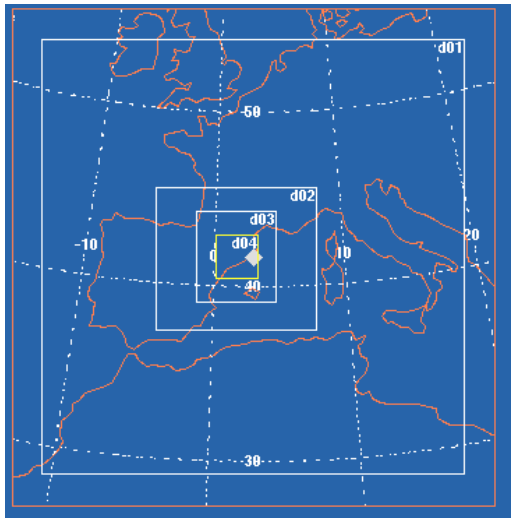


Year 2011
EEA, 2013

Methodology: air quality modelling system

Air quality modelling system:

- Meteorological model (e.g. WRF-ARW)
- Emission model (e.g. HERMES)
- Air quality model (e.g CMAQ)
- Others: mineral dust model (e.g NMMB/BSC-Dust), ocen and wave models, etc.

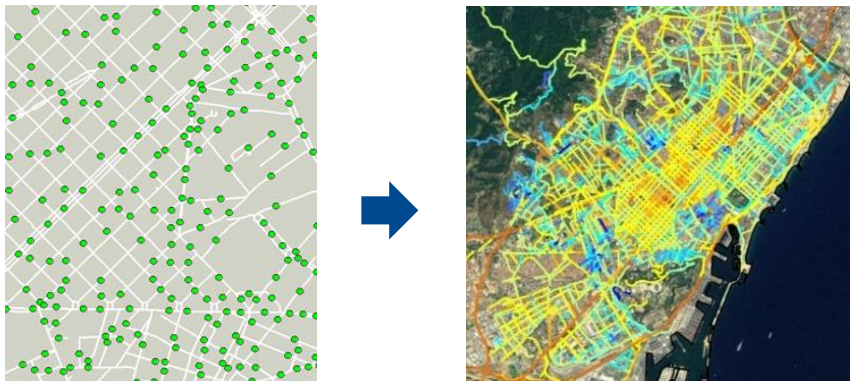


Configuration:

- High spatial (1x1 km^2) and temporal resolution (1h)

HERMES: Bottom-up emission model for Spain 1x1 km^2 and a temporal resolution of 1 h

Baldasano et al., 2008; Guevara et al, 2013



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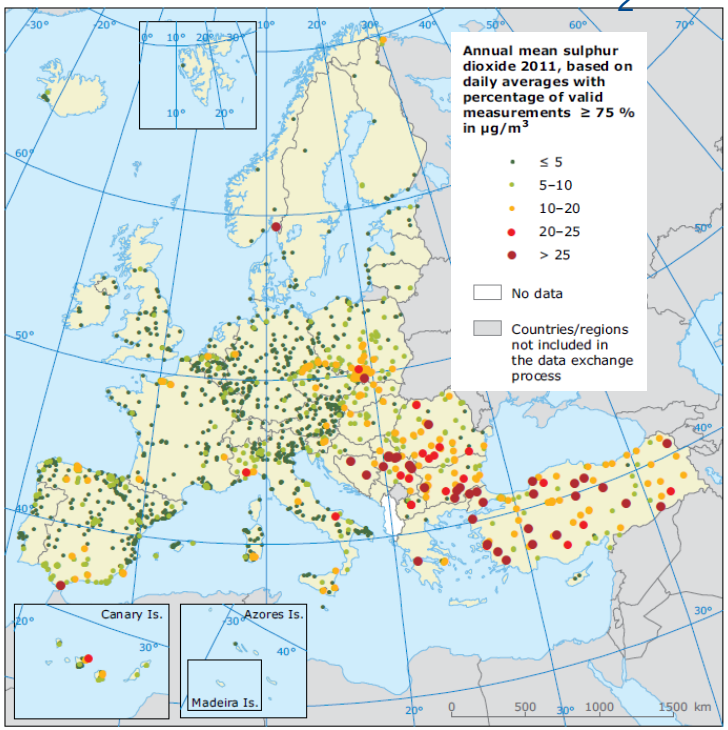
Santa Cruz de Tenerife, atmospheric dynamics

Singular characteristics of Santa Cruz de Tenerife:

- The interaction between the complex topography of the island of Tenerife (3718m) and trade winds.
- Breezes cycles due to the coastal location.
- Thermal inversion at relatively low altitudes that hinders convective motions.

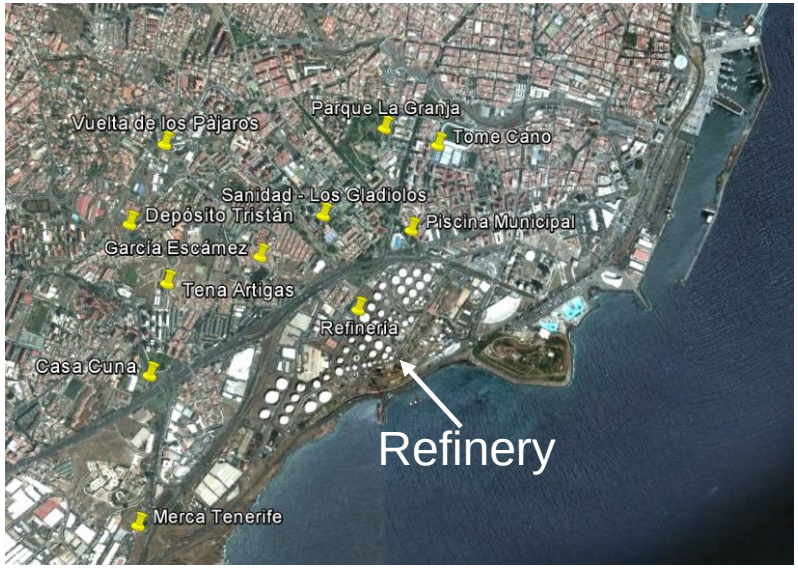
Annual mean concentration of SO_2 in 2011

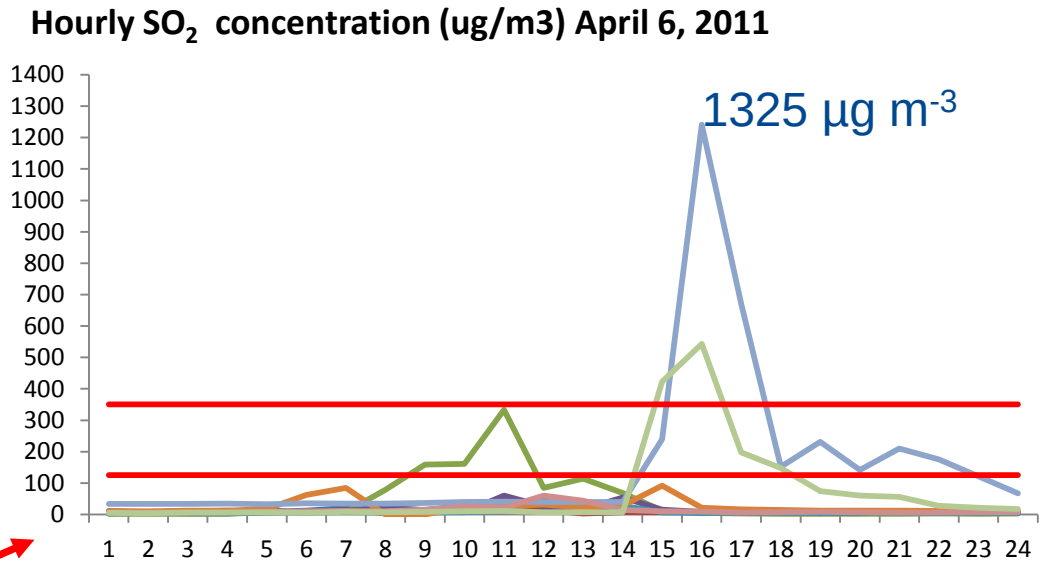


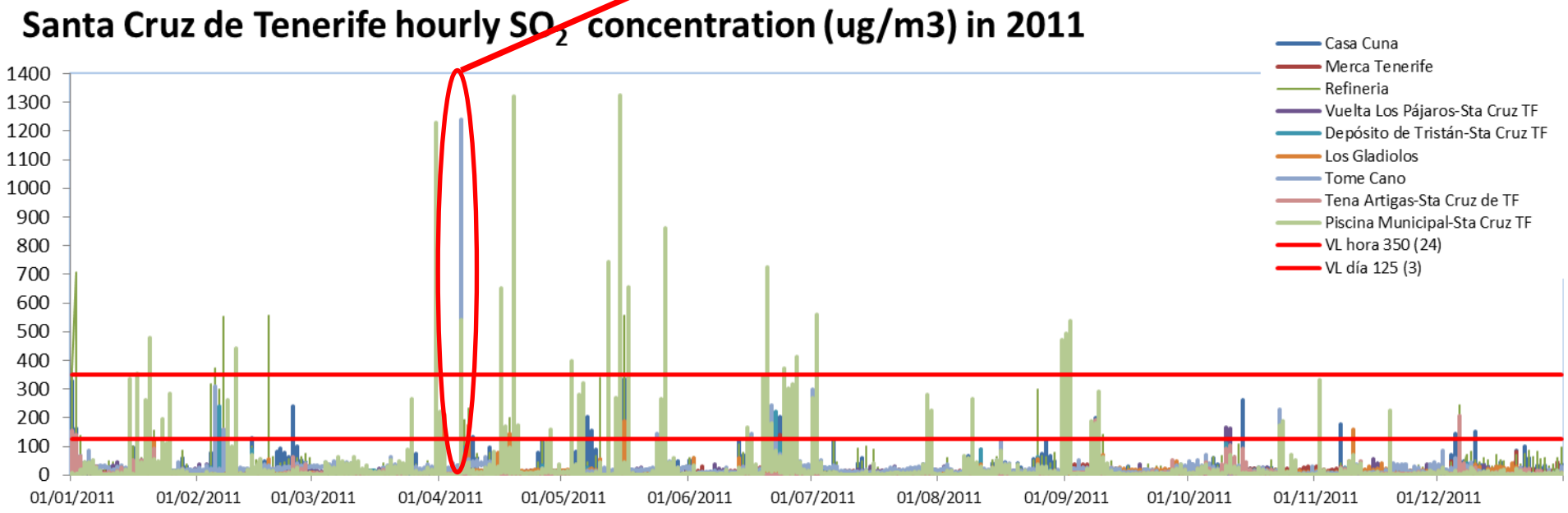
Dust storm over Canary Islands

Source: Terra-MODIS

Measured air quality concentration. SO_2.







Results. Air quality levels. The impact of the refinery

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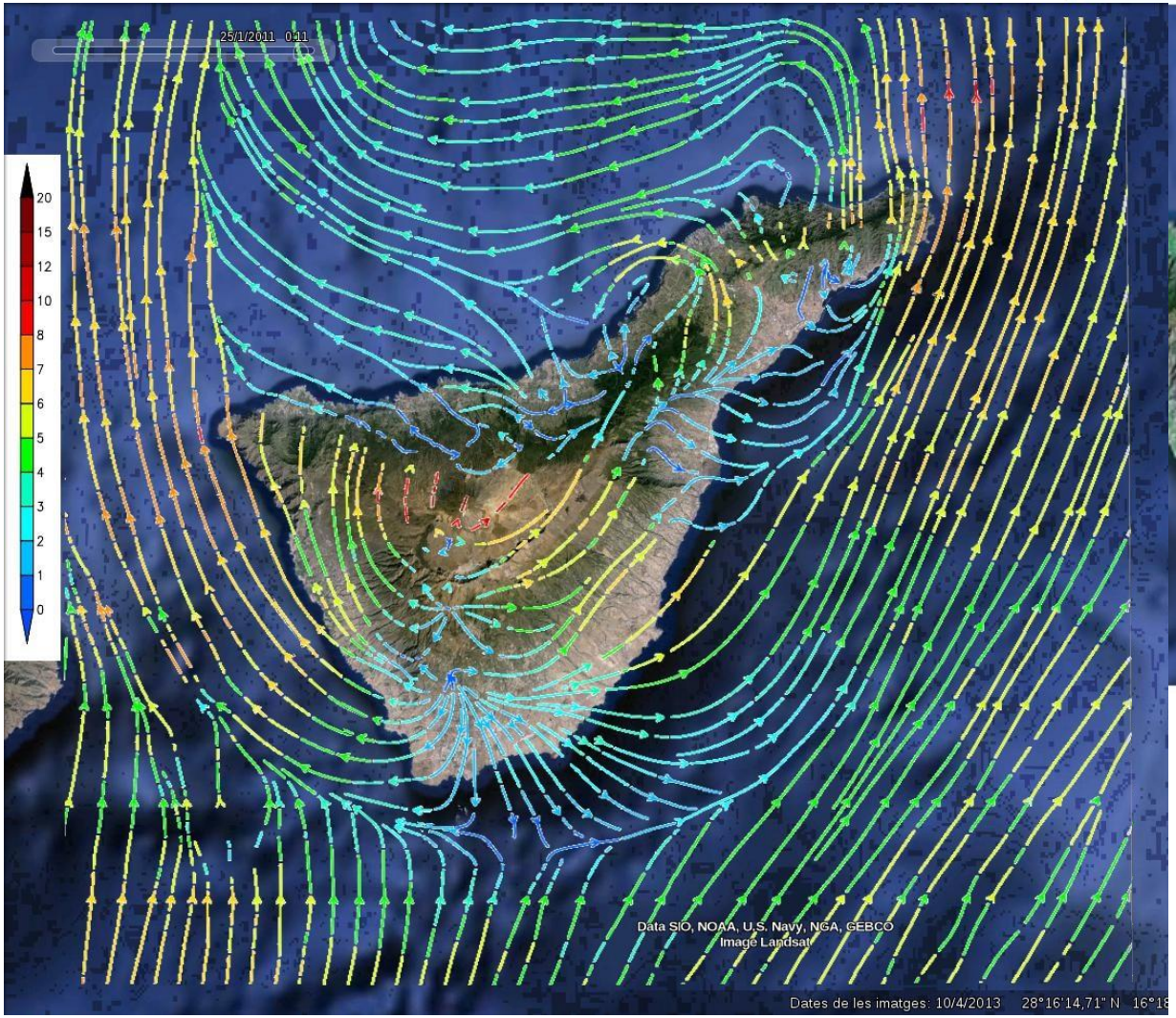
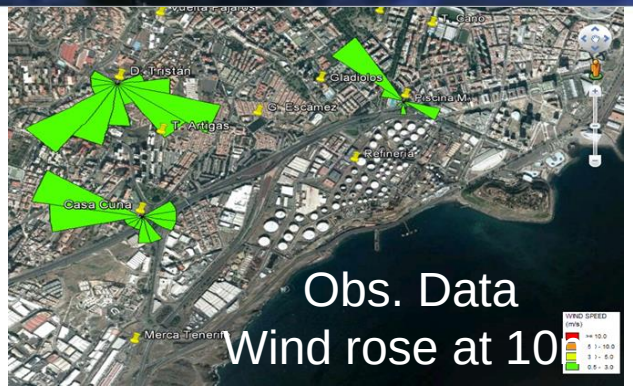
23 UTC WRF-ARW (1 x 1 km^2)



West (24th January 2011)



Air quality results. Primary area of influence of the refinery

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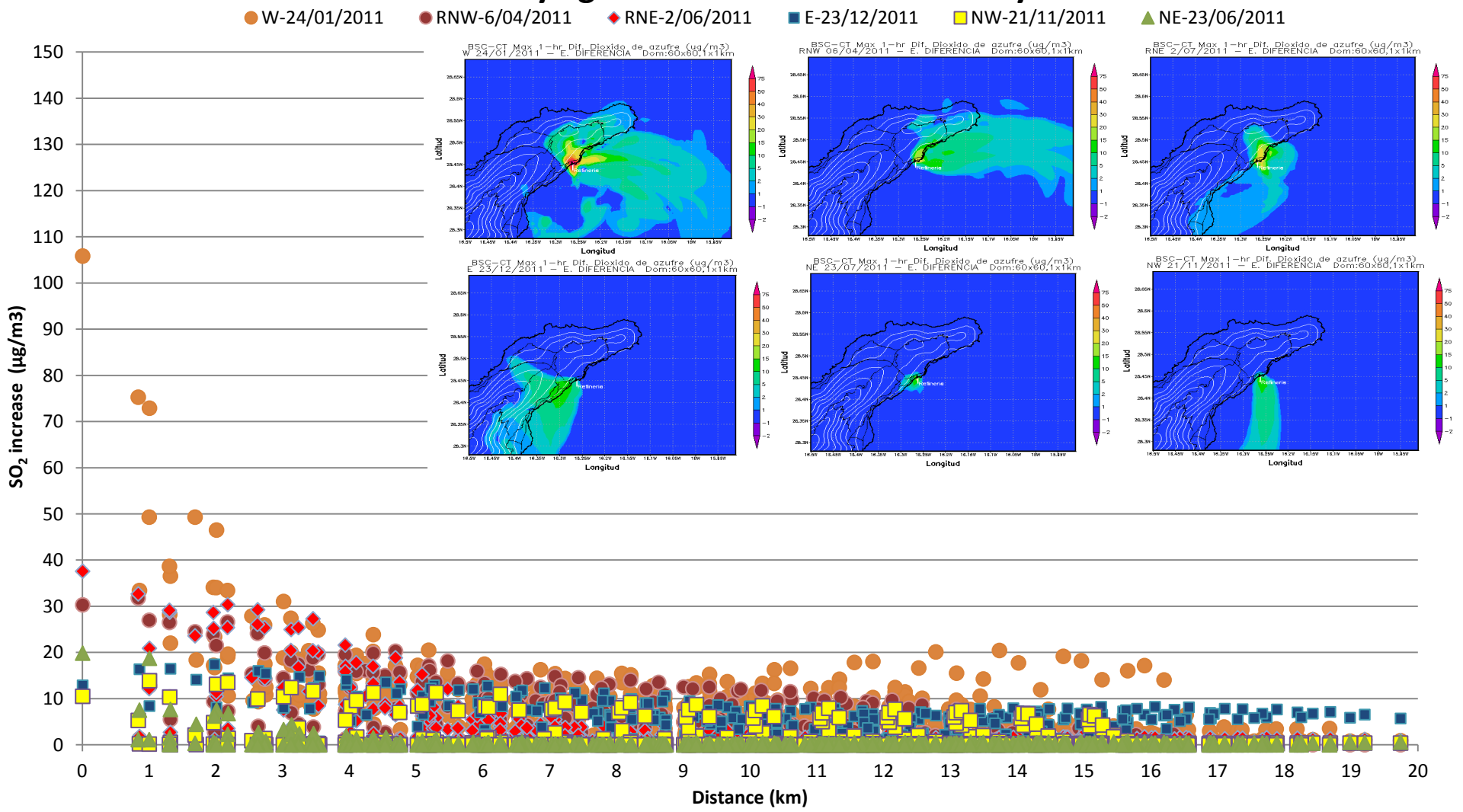
Maximum hourly increases of SO_2 due to the emission from the Tenerife refinery against distance to the refinery



(Baldasano et al., 2014)

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CALIOPE air quality operational forecasts

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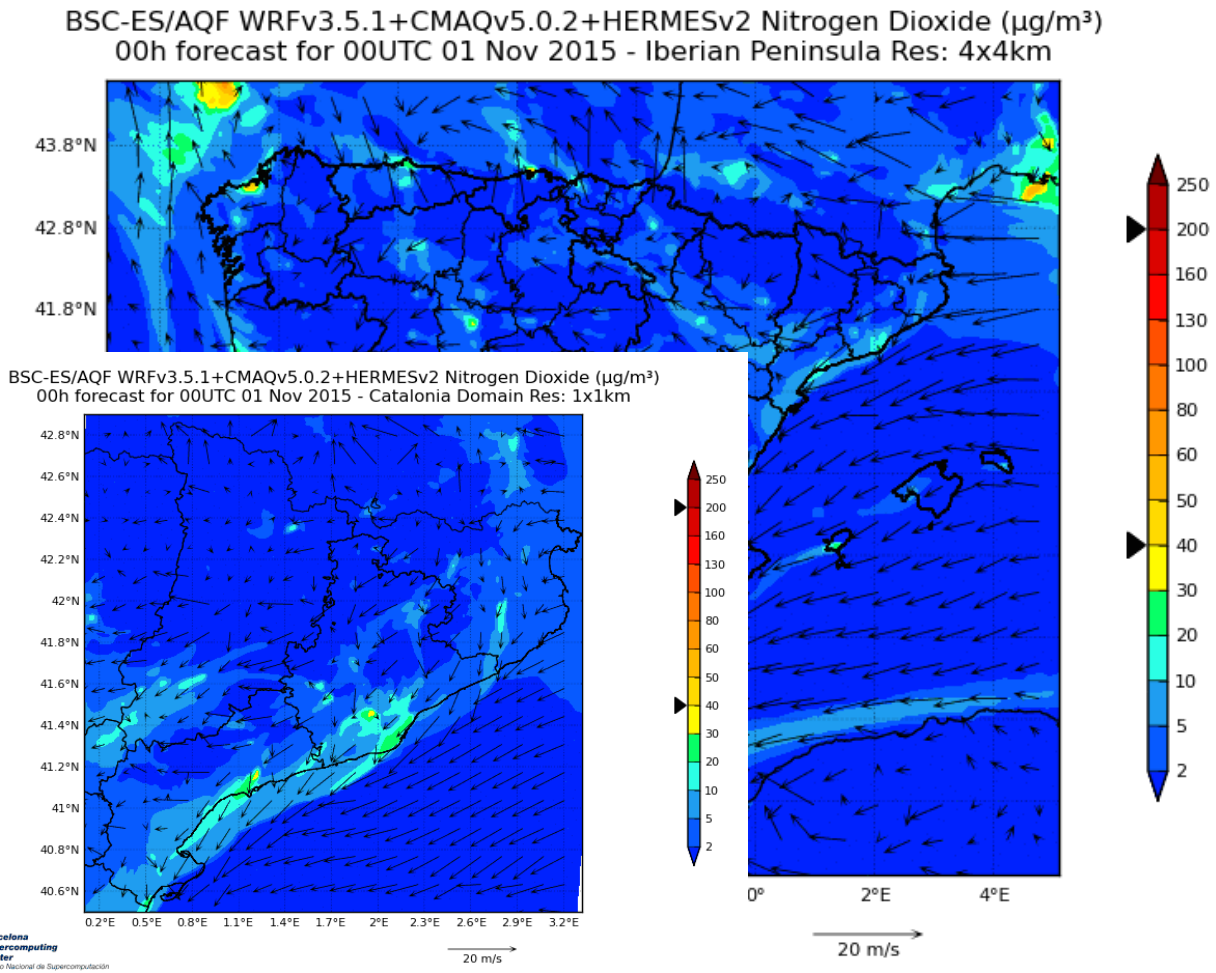
Provides air quality related information for the coming days and for the application of short term action plans for air quality managers.



Information is delivered using both online or custom applications:

www.bsc.es/caliope

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Fleet electrification

Fleet electrification: Replacement of internal combustion vehicles by electric vehicles

	Fuel red.	Autonomy
Micro-hybrid	5-10%	
Mild-hybrid	10-20%	
Full-Hybrid (HEV)	20-30%	2 km
PHEV	35-85%	20-80 km
Range Extender	65-100%	50-120 km
BEV	100%	80-300 km
Fuel cell vehicle (FCEV)	H2	400-600 km

Hybrid electric vehicles (HEV)

e.g. Van Hool Exquicity

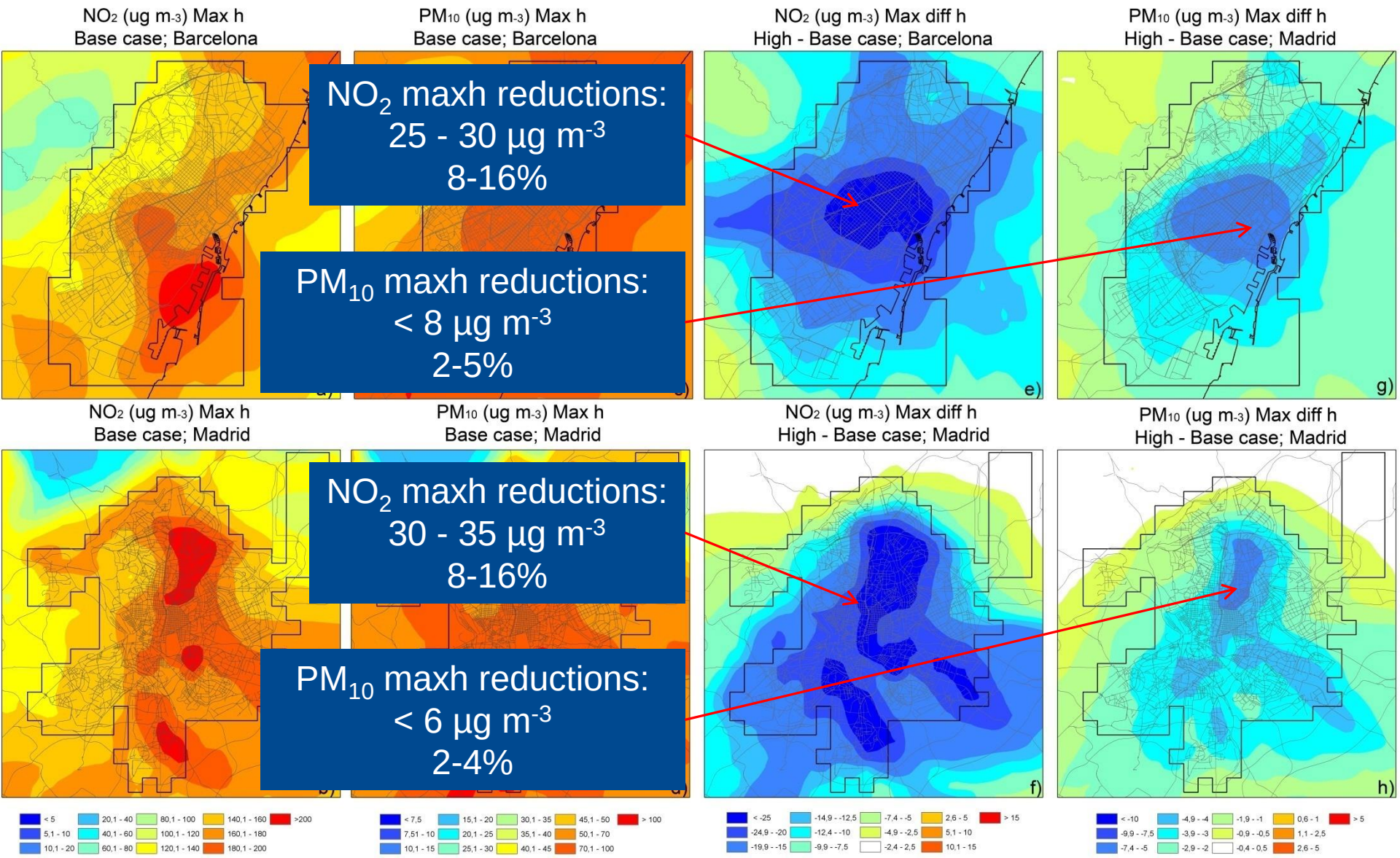
Plug-in electric vehicle (PHEV)

e.g. Piaggio MP3 Hybrid 300

Battery electric vehicle (BEV)

e.g. BMW i3

Fleet electrification. Air quality impacts



(Soret et al., 2014)

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Climate

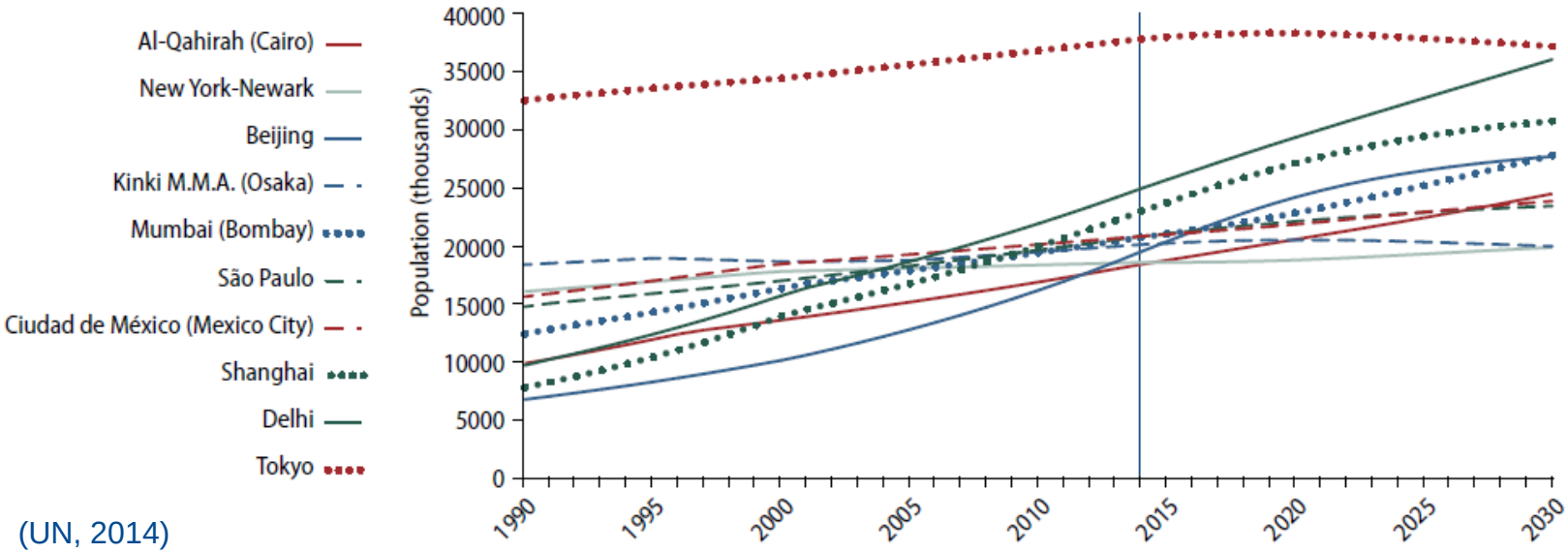
Climate change. Exposure and vulnerability of urban areas

Exposure and vulnerability are dynamic, varying across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors.

Rapid urbanization and the growth of megacities, especially in developing countries, have led to the emergence of highly vulnerable urban communities.

For example, coastal cities, including cities in small islands and megadeltas, are exposed and vulnerable to climate extremes in both developed and developing countries.

The ten largest urban megacities. Urban population trends



(UN, 2014)

Coastal megacities: The case of Mumbai

At present, Mumbai is the city with the largest population exposed to coastal flooding.

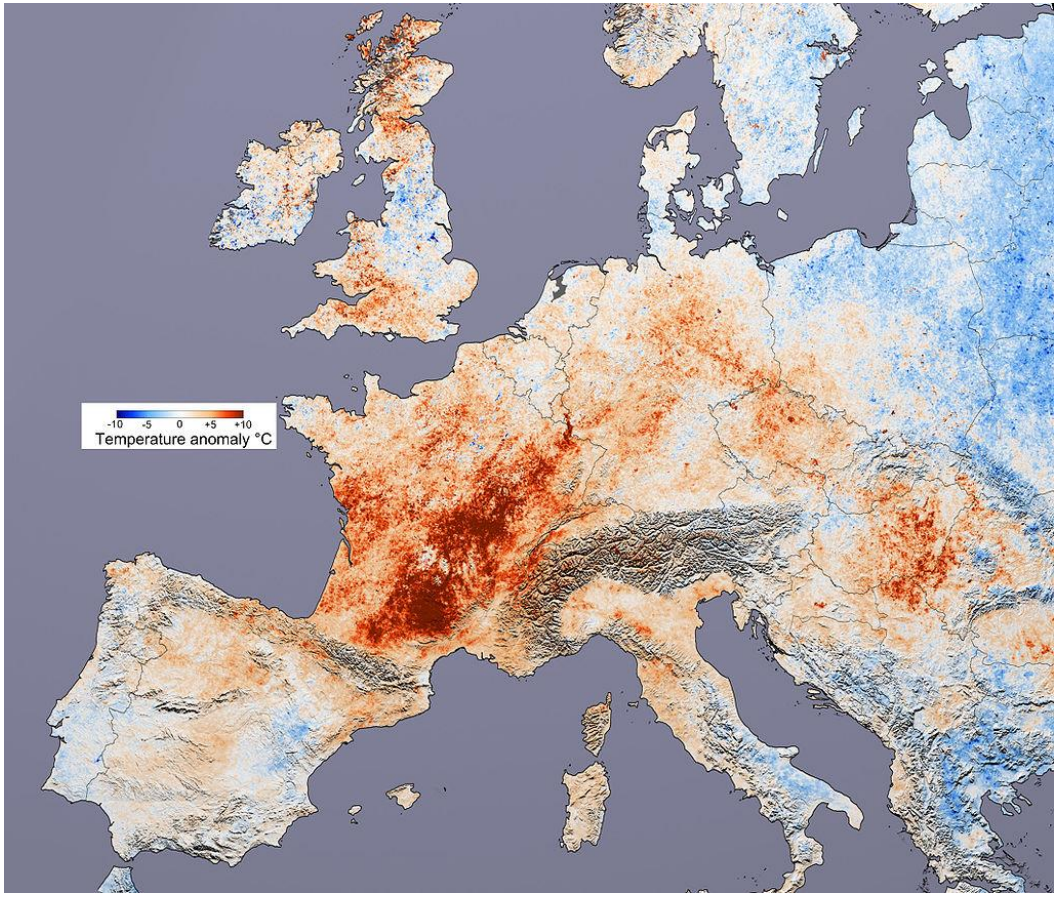
In July 2005, Mumbai, India, was struck by an exceptional storm. In one 24-hour span alone, the city received 94 cm of rain, and the storm left more than 1,000 dead, mostly in slum settlements.

Attributing causes of changes in monsoons is difficult due to substantial differences between models, and the observed maximum rainfall on India's west coast, where Mumbai is located, is poorly simulated by many models. (IPCC, 2012)

Heat waves

Global climate change is likely to be accompanied by an increase in the frequency and intensity of heat waves, as well as warmer summers.

Heat waves have a much bigger health impact in cities than in surrounding suburban and rural areas. Urban areas typically experience higher—and nocturnally sustained—temperatures because of the "heat island" effect.



Difference in average temperature (2000, 2001, 2002 and 2004) from 2003, covering the date range of 20 July – 20 August

Source: (MODIS) on NASA's Terra satellite

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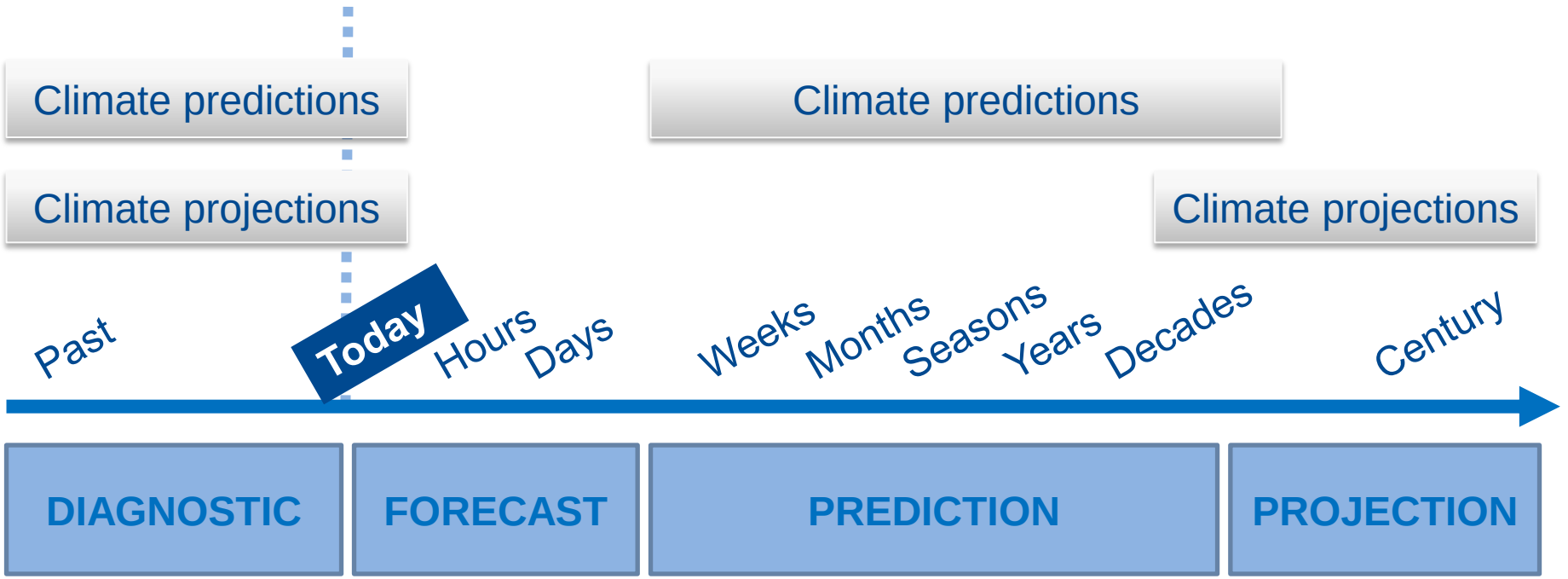
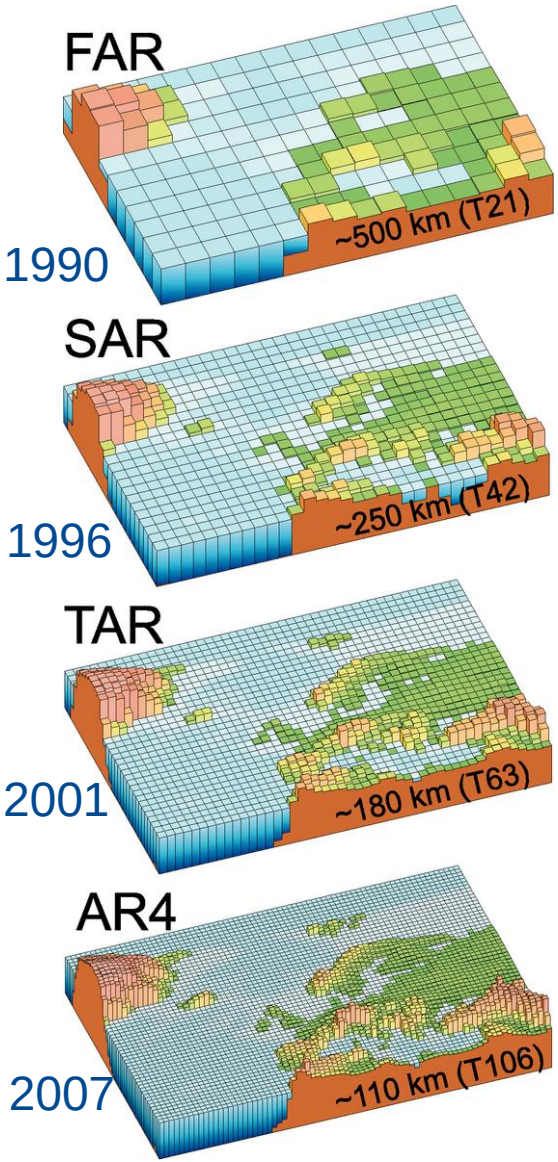
Climate prediction and projection systems

The interactions between the various components of the system play a crucial role in the dynamics of climate. E.g. EC-EARTH modelling system:

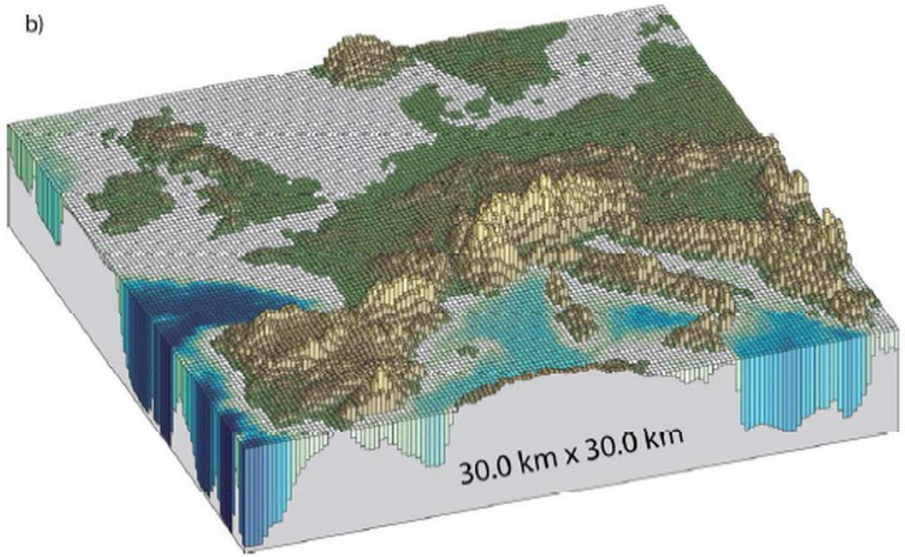
- IFS: representing the atmosphere
- NEMO: representing the ocean
- LIM: representing the sea-ice
- HTESSEL: representing the continental surfaces and vegetation
- TM5: representing the atmospheric chemistry



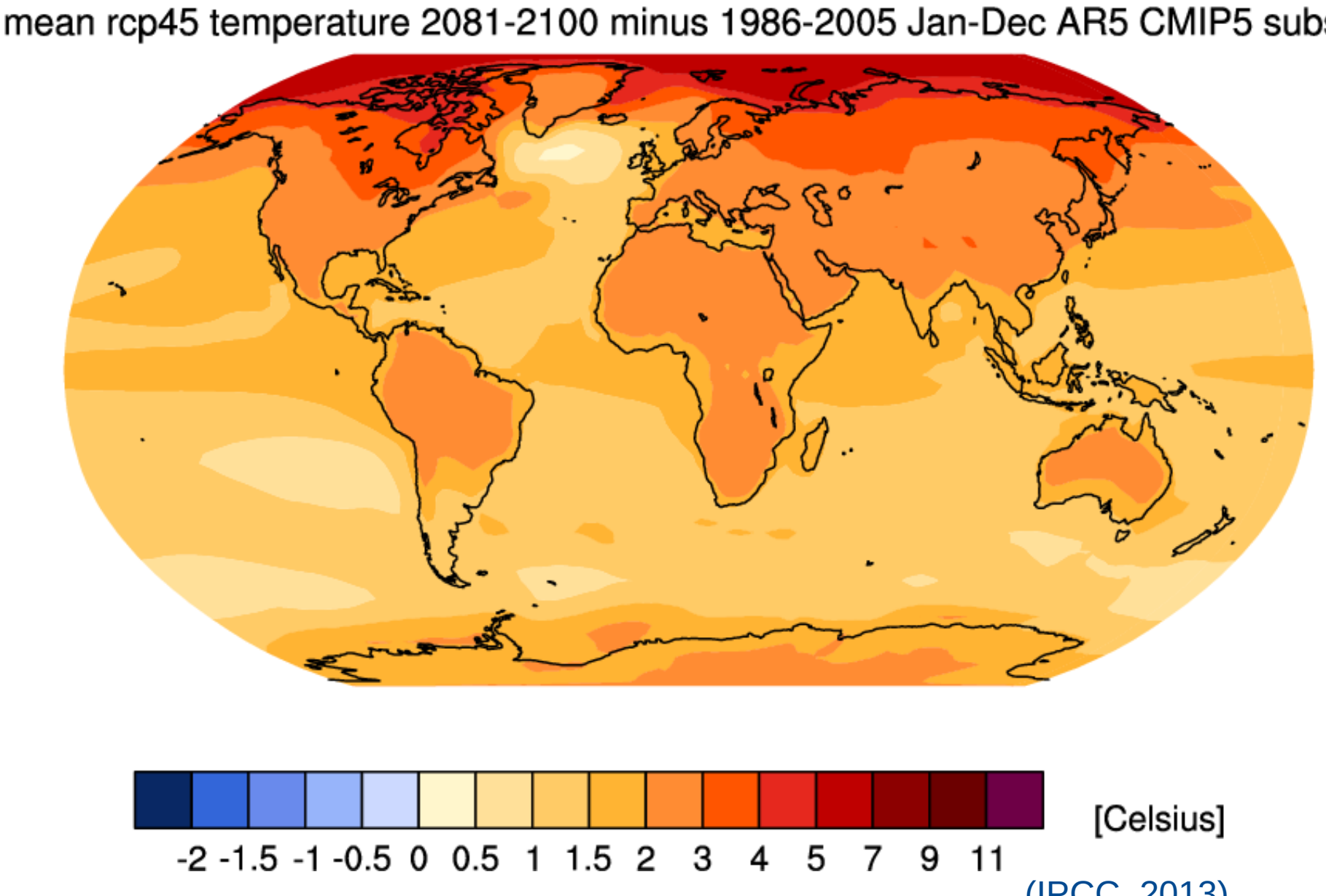
Climate prediction and projection systems. Spatial resolution



Climate modelling: resolution of the climate models used in the IPCC



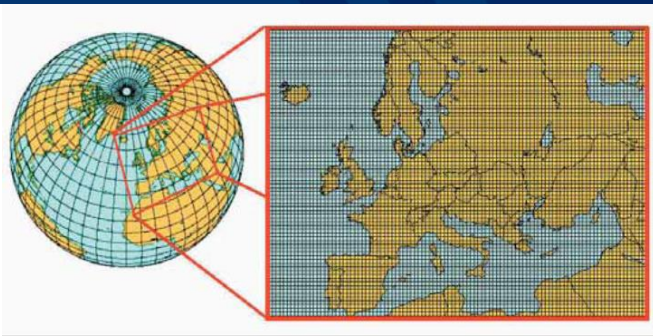
Climate prediction and projection systems. Spatial resolution



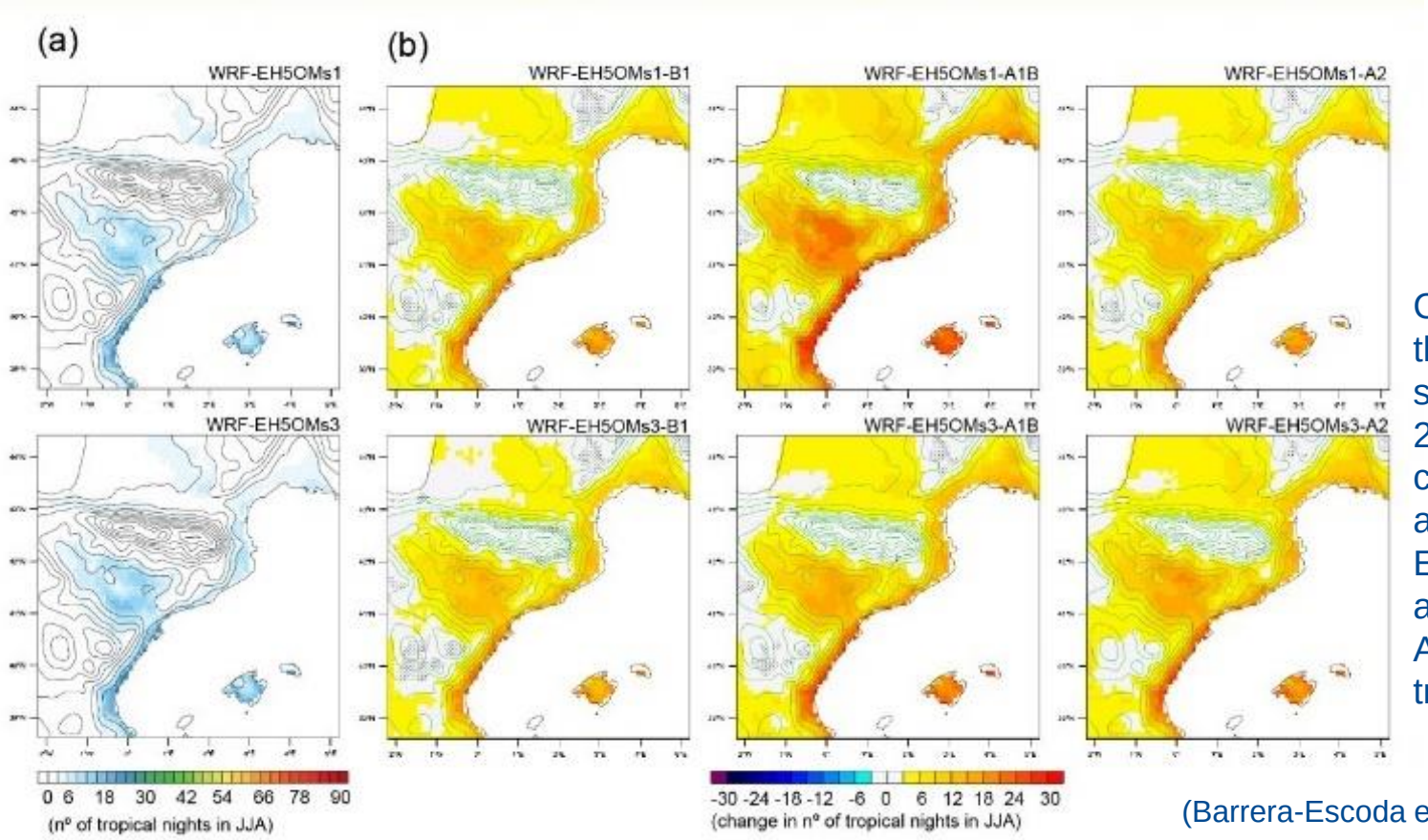
(IPCC, 2013)

Downscaling techniques

Dynamical downscaling of climatic temperature and precipitation trends. This work aims to provide an assessment of temperature and precipitation projections for mid-21st century in the North Western Mediterranean Basin (NWMB) at high resolution.



Global models Regional models



Climatological mean from the WRF-EH5OMs1 and s3 simulations for 1971–2000 and projected changes for 2021–2050 as derived from WRF-EH5OMs1 and s3 according to B1, A1B and A2 scenarios for the tropical nights number.

(Barrera-Escoda et al., 2013)

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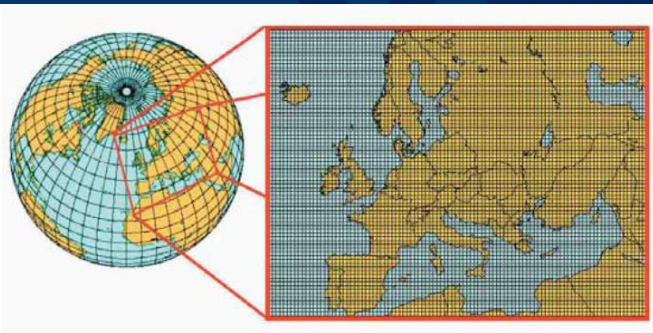
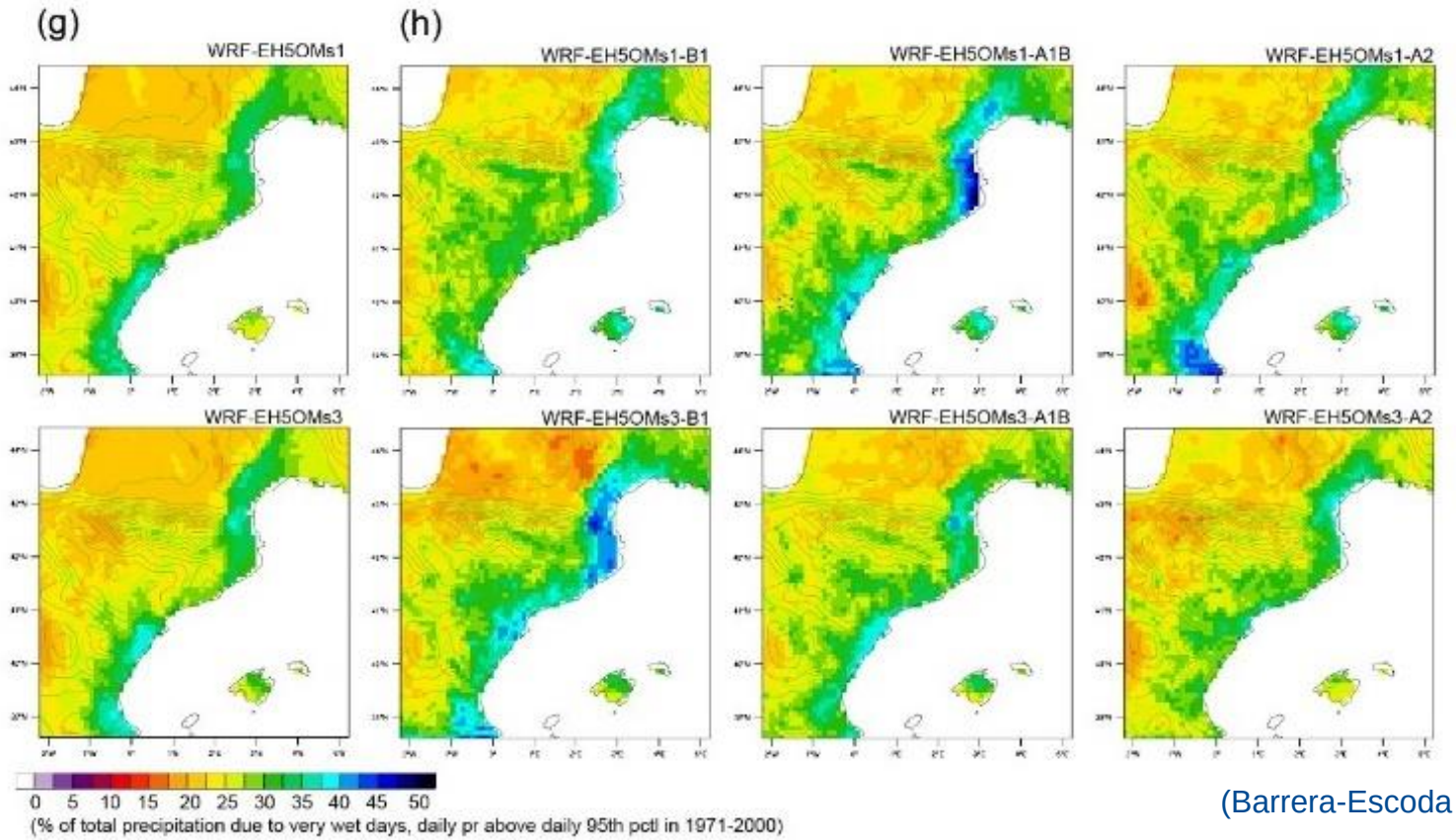


Global models Regional models



Climatological mean from the WRF-EH5OMs1 and s3 simulations for 1971–2000 and projected changes for 2021–2050 as derived from WRF-EH5OMs1 and s3 according to B1, A1B and A2 scenarios for the contribution of very wet days to total precipitation amount.

(Barrera-Escoda et al., 2013)

Future work

Further understanding of urban processes.

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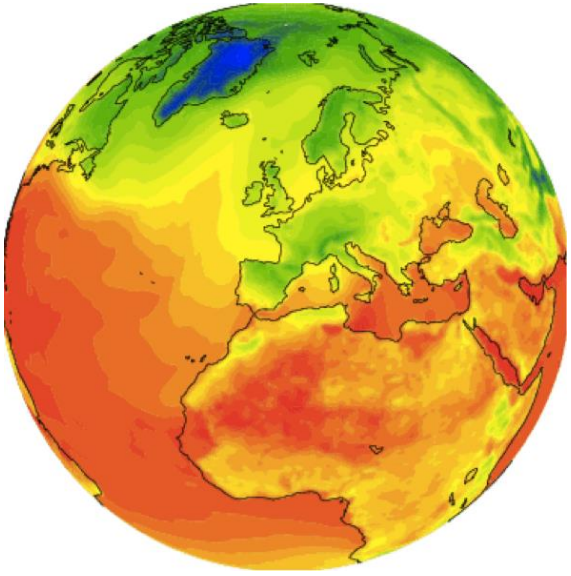
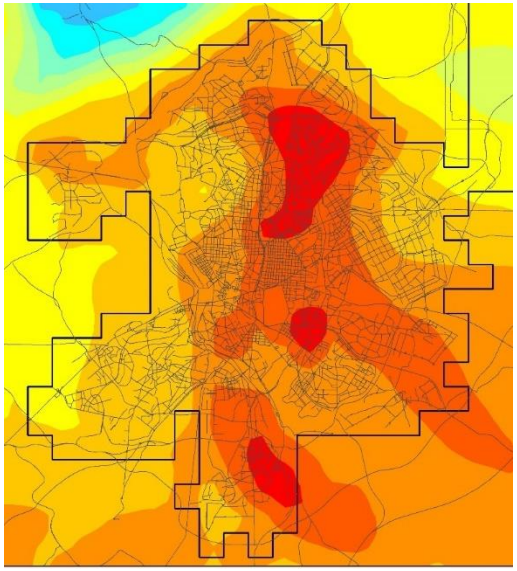
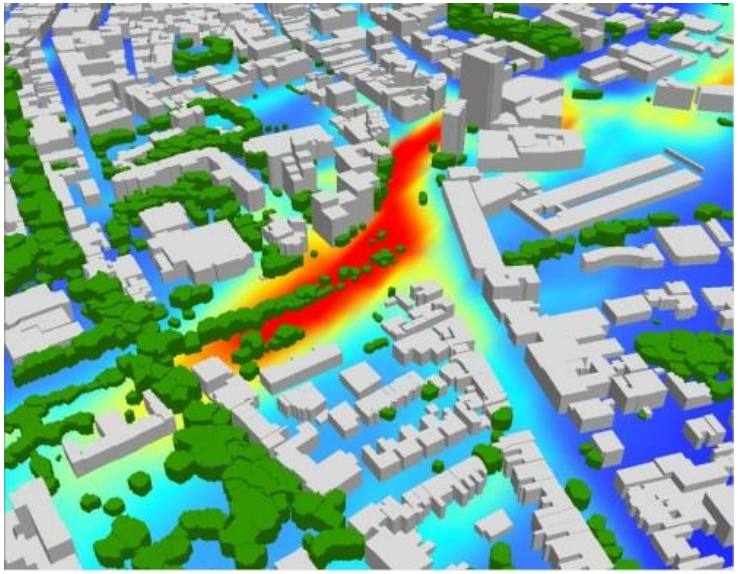
Further understanding of local scales processes to allow the assessment of sustainable management of urban areas within the SmartCities context by using two key-elements:

- microscale atmospheric models
- observations from smart infrastructures



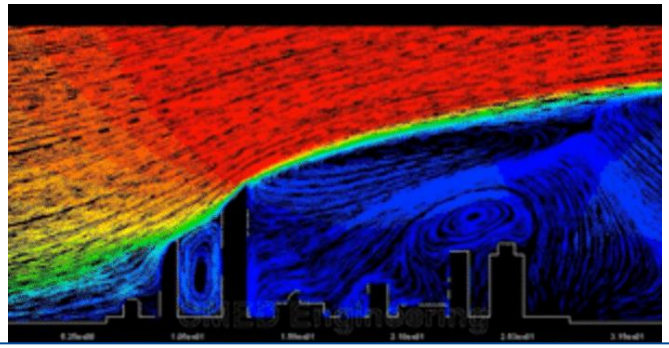




From global to regional scales

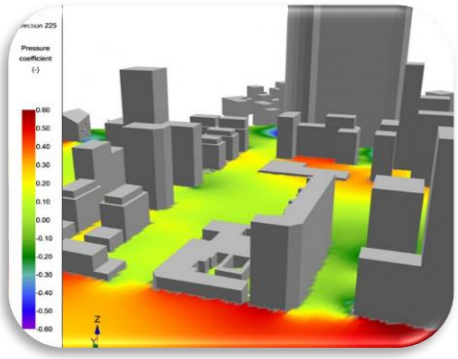
Next step: microscale

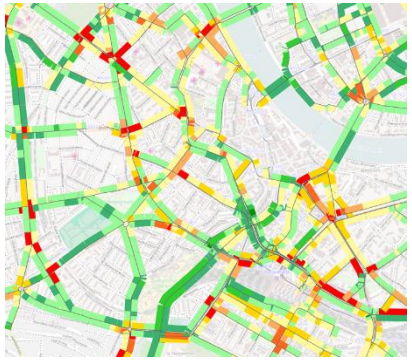
Air quality assessment at urban scales. Strategy: interdisciplinar approach

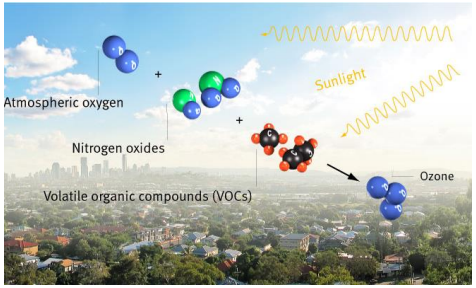


CDF air quality at microscale

Meteorological core	Emission module	Air quality module	Smart infrastructures







CASE dep. + Earth Sciences dep. + Computer dep.

Conclusions

Conclusions

- Air quality and climate model systems are an important tool to understand and analyze earth system processes.
- Air quality modelling allow relating emission sources and meteorological processes with changes in air quality levels.
- Air quality modelling can be applied in diagnostic studios, air quality forecast systems and air quality management plans.
- Air quality modelling systems: their spatial resolution (up to 1x1 km^2) and configuration (e.g. urban land use categories within the meteorological models) allow for assessing air quality related impacts in urban areas.
- Climate modelling systems have difficulties to resolve urban related processes.

Satellite view of Earth at night. 1-4% of land surface is urban.
More than 50% of world's population lives in urban areas.

Thank you!

For further information please contact
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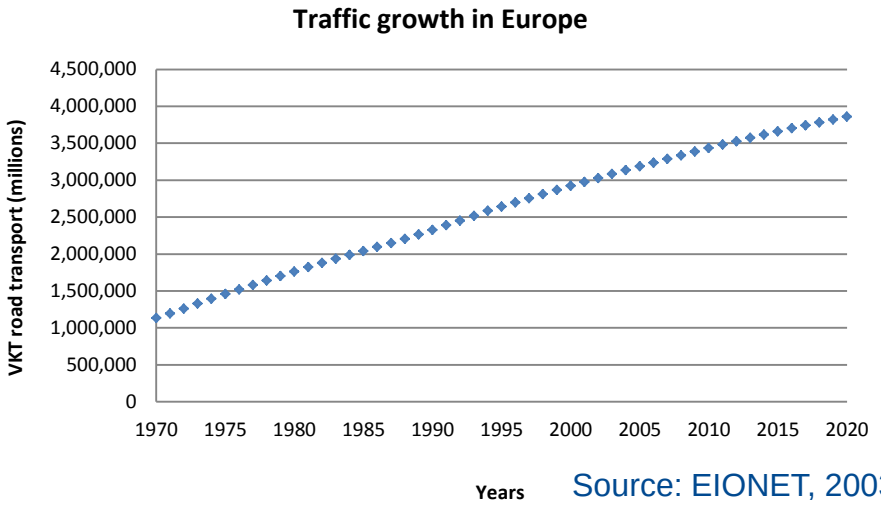
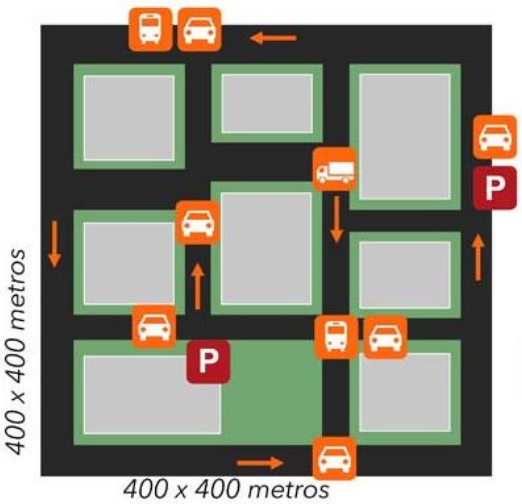
Mobility management

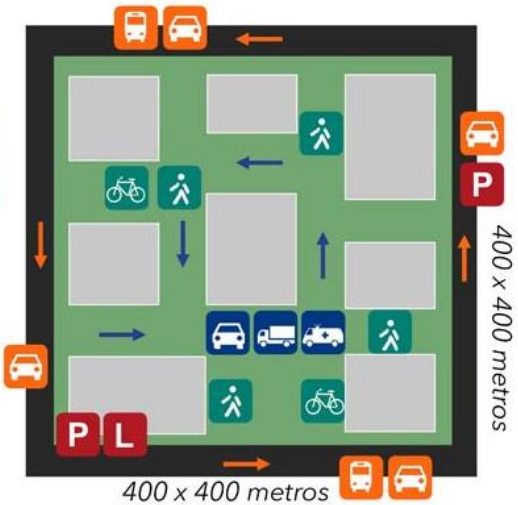


Source: EIONET, 2003

Implementation of Superblocks in Barcelona

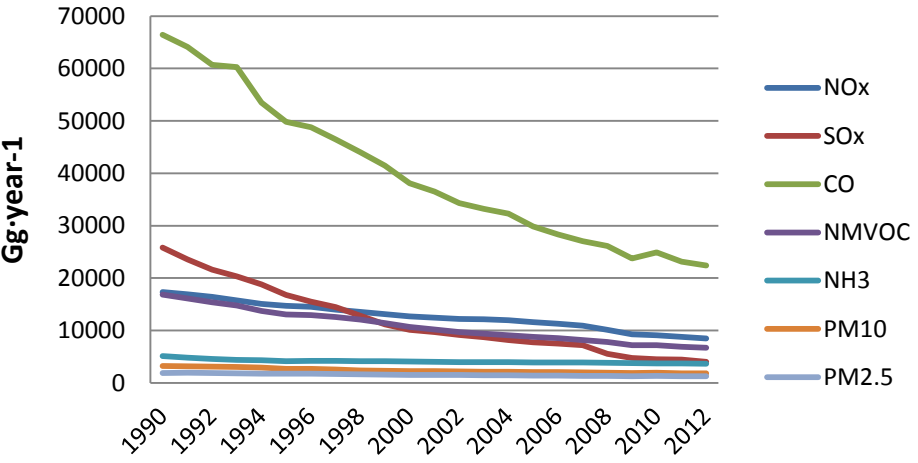
Source: BCNEcologia





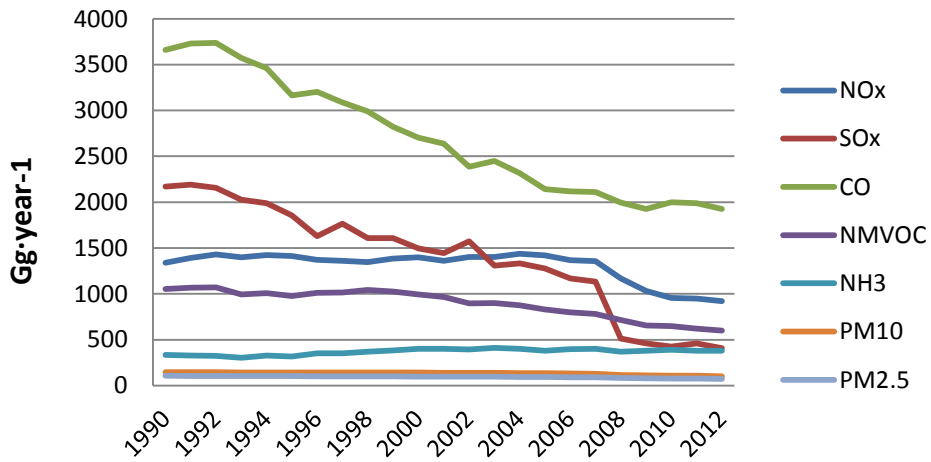
Emission trends

Emission trends in Europe (EU-28)



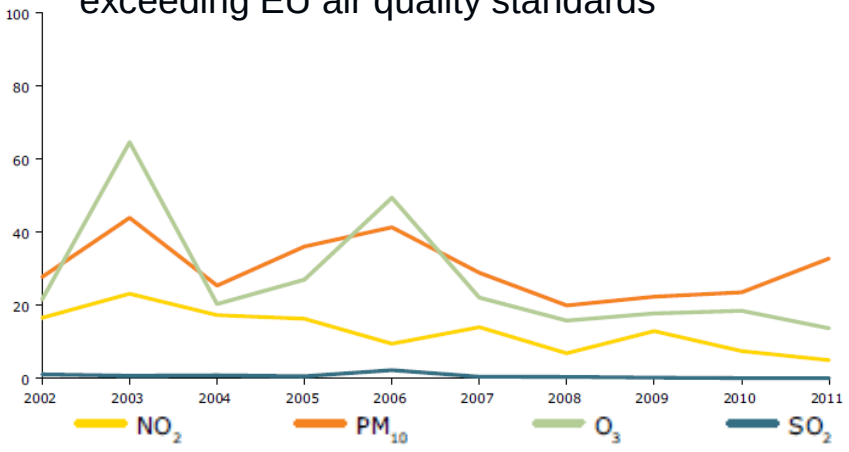
Emission have dropped considerably but air quality still needs to improve

Emission trends in Spain



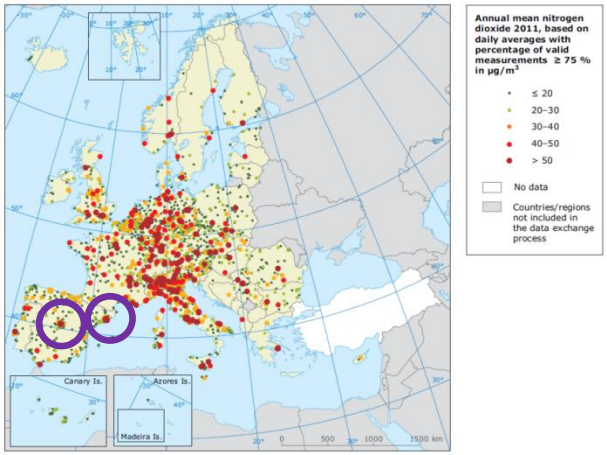
A significant proportion of urban population is exposed to air quality concentrations exceeding EU air quality standards

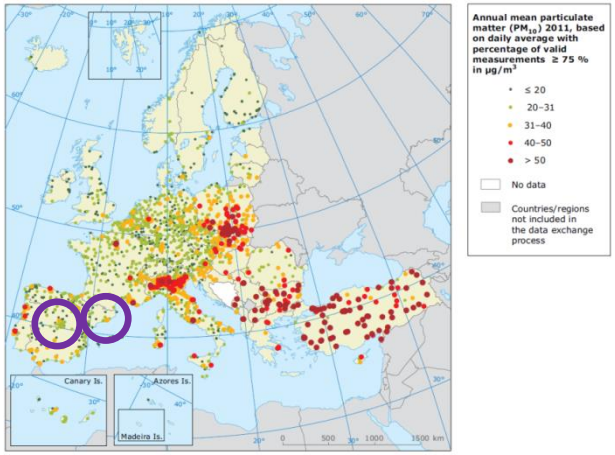
% of urban population exposed to air pollution exceeding EU air quality standards



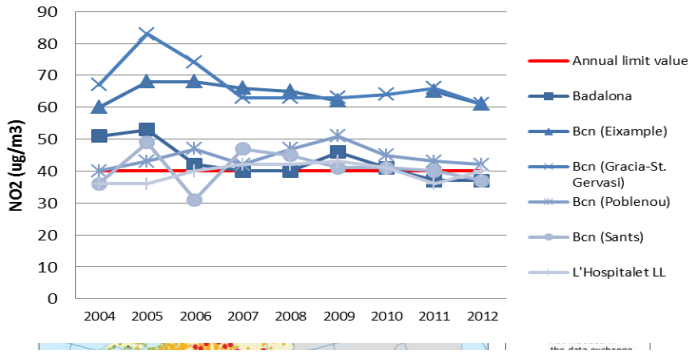
Source: EEA, 2013

Air quality in Europe

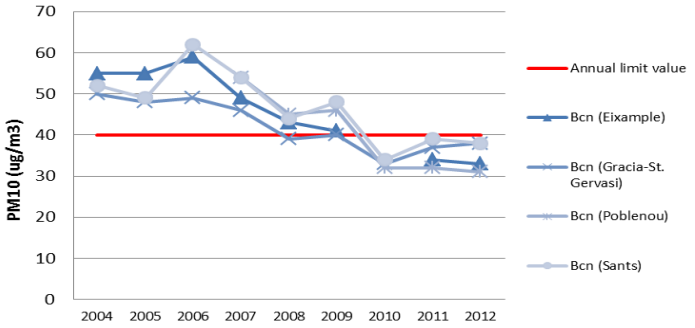




Barcelona NO_2 trends; yearly average concentration

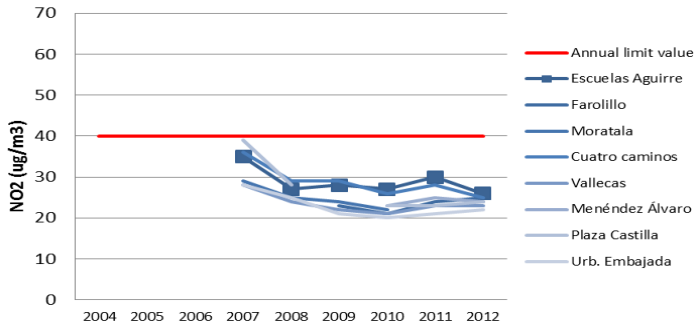


Barcelona PM_{10} trends; yearly average concentration



Madrid NO_2 trends; yearly average concentration

Madrid PM_{10} trends; yearly average concentration



H O_3

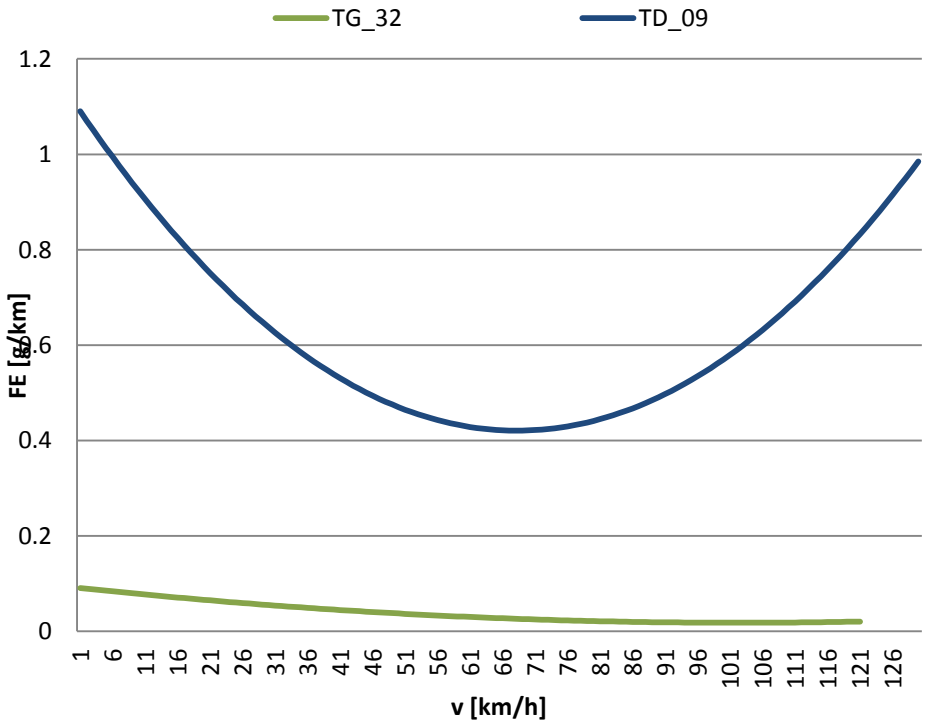
Year 2011
EEA, 2013

Emission factors. Diesel and gasoline

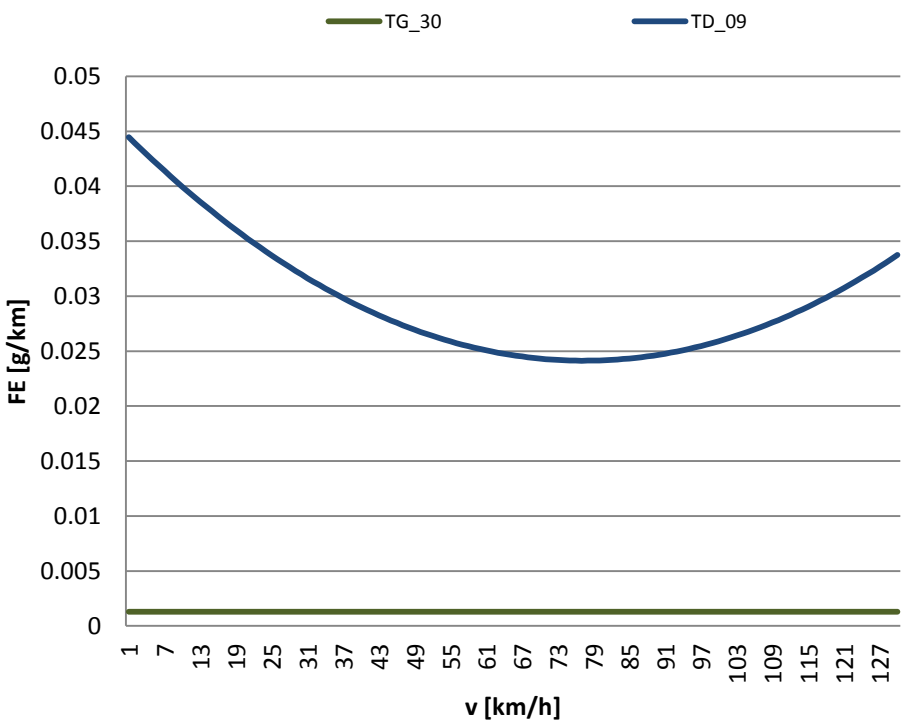
The Mayor of Paris has announced radical plans to ban diesel cars from the French capital by 2020 due to concerns about how much pollution the cars cause (France has the highest number of diesel cars in Europe). And the Mayor of London is also considering similar solutions.

She also said that the city would have more semi-pedestrianised areas with special zones introduced at weekends.

NOx PC Gasoline and Diesel

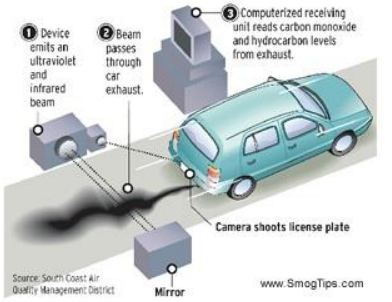


PM- PC Gasoline and Diesel



Improvements for the road transport emissions

Remote Sensign Device



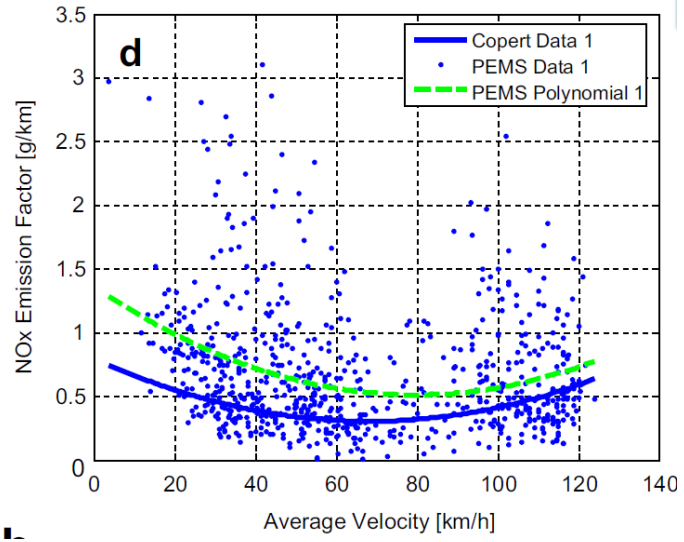
	RSD [g/km]	COPERT [g/km]	RSD/COPERT [%]
NO_X	1,172	1,005	+16,6%
PM_{10}	0,124	0,070 (*)	+75,5%

AB (2010)

Portable Emission Measurement System

Kouridis et al. (2013)

EF NO_x - Euro 5 diesel PC



Air quality and climate change. Emissions

Global impact: Climate Change

Measures to reduce emissions

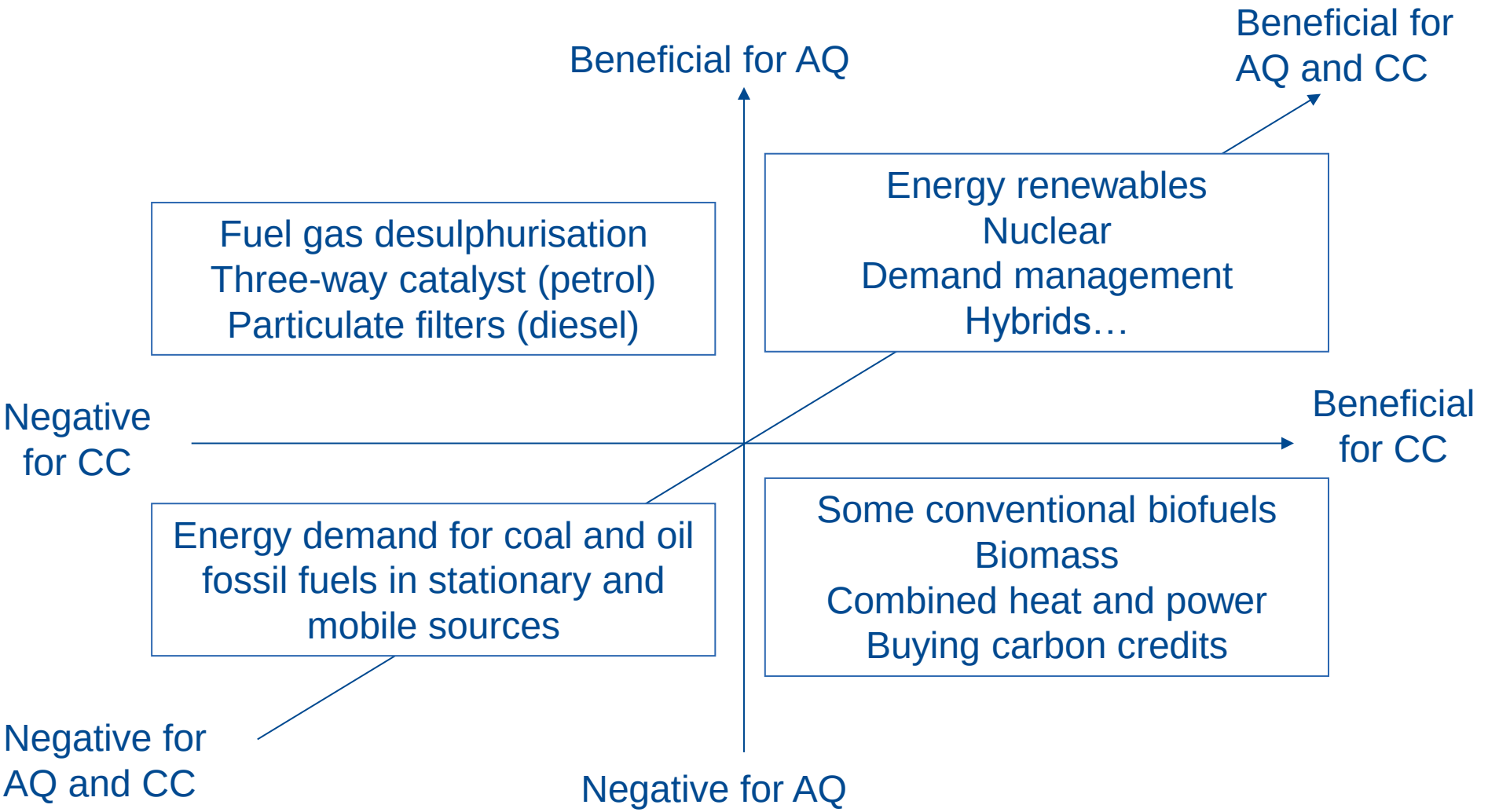
Local-regional impact: air quality

GHG: CO_2eq

Atmospheric pollutants: NO_2, etc.

Air quality and climate change. Measures to reduce emissions

Air quality (AQ) and climate change (CC) synergies and trade-offs



(Source: adapted form Drefra, 2010)

Areas of study: Barcelona and Madrid